International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 12
DOI: https://doi.org/10.17762/ijritcc.v10i12.5893
***Article Received**: 13 October 2022 **Revised**: 06 November 2022 **Accepted**: 10 December 2022*

Frequency Reconfigurable Microstrip Patch Antenna for Multiband Applications with Shunt-Series MEMS Switch

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Abstract—The wireless communication system is well developed and lots of antennas are designed and fabricated for this application. Still, the evolution of the communication system, the performance of the antenna is required to enhance to adopt the present era. The design of the antenna is most important for the performance of the antenna. Therefore, this work is designed and developed a novel antenna design for wideband application by utilizing frequency reconfigurable technique. The proposed work utilized microstrip patch antenna for the application of wideband and the Shun-series MEMS switch is applied for switching the frequency. The proposed antenna is designed with two switches and investigated with the switching conditions like ON-ON, OFF-ON, and OFF-OFF. The performance of the proposed antenna is validated by utilizing the antenna performance metrices such as Return loss, bandwidth, gain, VSWR, and radiation pattern for each switching condition. The simulation results are shows that the proposed antenna design with shunt-series MEMS switch is effectively performed and it is most suitable for the application of wireless communication system..

Keywords- Microstrip patch antenna; RF MEMS; Shunt-series; Frequency reconfigurable antenna; Wireless communication system.

I. INTRODUCTION

In this digital environment, wireless communication system playing an important role for the communication and data transmission without utilizing cables, wires, or any other electrical conductors. Nowadays, the wireless communication is used in all over the world which can able to transmit the data over a long distance also. This advanced communication system is mostly applied in many applications such as (i) Digital audio broadcasting (DAB) which is transmitting the news, weather report, music, and other broadcast data with 1.5 Mbit/s, (ii) Mobile phones which are provide voice communication and data connectivity with 384kbit/s, (iii) Bluetooth which is a wireless technology used to transmit data and files and it is act as a complement to Wi-Fi [1]. In recent days, antennas are considered as the most important devices for the wireless communication system which is preferable for transmit and receive radio frequency signals. It is also capable of operating on multi wireless bands which is recommended for the radio and satellite communication. Still, the speed of transmitting and receiving the data is the challenging part of the antenna [2]. There are lots antennas are developed for the wireless communication system. Yet, the printed type antennas are widely utilized for the wireless communication due to its low-profile nature and simple in design. The main advantage of this type antenna is easily adopted with the related electronic devices. Generally, this printed type antennas are designed and fabricated based on printed circuit technology [3].

Printed antennas are implemented broadly in the wireless communication because of their low profile, low manufacturing cost, and light weight. Mostly, these antennas are employed in the wireless communication systems like WiMax band, mobile, Satellite communication, GPS navigation, and WLAN band [4]. For this communication system, several printed type antennas are widely utilized, they are loop antennas, printed monopole and dipole antennas, planner inverted F-shaped antennas (PIFA), slot antennas, and microstrip patch antennas (MPA). From these types, the microstrip patch antenna is most preferred for the wireless communication such as remote

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sensing radar, telecommunication systems, perimeter surveillance, etc. due its compactness and flexible design with low fabrication cost [5]. The development of microstrip patch antenna (MPA) was initiated in the late 1970s and the component establishment was accomplished in the early 1980s. The MPA is designed and fabricated in various shapes such as rectangular, circular, ring, square, etc. [6]. Moreover, it has some main advantages like (i) the development of MPA is simple due to its theory is well known, (ii) the fabrication of this antenna is easier because the design structure is simple and they can able to integrate with any electronic devices, (iii) while the fabrication of MPA, the low-cost substrate can also be used to minimize the fabrication cost, and (iv) the appearance of this antenna is rugged and it have low profile. These advantages are the main reasons for broad utilization of this antenna in real-time applications like GPS receivers, personal digital assistance (PDA), telecommunication, etc. [7].

For the wireless communication system, ultra-wideband antenna is widely utilized which has the frequency range between 3.1 to 10.6 GHz. The advantage of this antenna is it can able to provide high potential communication system with high-speed in short-range [8]. The performance of these antennas is validated with the help of metrics like Return loss, VSWR, Gain, Radiation pattern, Bandwidth, etc. [9]. To enhancing the parameters, lots of techniques are utilized still reconfigurable techniques are mostly preferred which concentrating on governing and improving the outcome of the antennas. The reconfiguration techniques are categorized into four types and they are named as radiation pattern reconfiguration, compound reconfiguration, polarization reconfiguration, and frequency reconfiguration [10, 11]. From these categories, the reconfiguration process difficulty is low in frequency reconfiguration compare to other reconfigurations. Here, the frequency is reconfigured with the help of switching mechanism [12, 13]. There are lots of switching mechanisms are existed in the present days for the frequency reconfiguration. Still, MEMS switching mechanism is widely utilized for the reconfiguration process and it is the advanced switching mechanism. This switch mechanism has some advantages like high frequency, minimum intermodulation distortion, wide band and much higher isolation. Generally, switching conditions are working based circuits like series connection and shut connection [14]. In MEMS switching mechanism, the circuit connection is categorized as series contact connection, series capacitive connection, shunt contact connection, and shunt capacitive connection. Still, the hybrid connection type like Shunt-series connection in the MEMS mechanism is playing a vital role to overcome the problems which are faced by the other connections [15]. This is motivating the presented work to propose a novel antenna design with better efficiency for the application of wireless communication system. The main objective of the proposed work is to develop a frequency reconfigurable microstrip patch antenna for the wideband application. Here, the frequency is reconfigured with the help of utilizing the Shunt-series MEMS switching mechanism and it will obtain better results.

This work is organized as, section 2 discussing the proposed design and configurations; section 3 discussing the design procedure and analyzing the simulation results; section 4 analyzing the comparison of each condition; and final section concluding the proposed work.

II. PROPOSED DESIGN AND CONFIGURATION

The proposed frequency reconfigurable microstrip patch antenna is designed on the basis of Microstrip patch antenna design equations. Here, the frequency is reconfigured with the help of utilizing Shunt-series MEMS switch which is the combination of two type switches. Moreover, the maxwell equation is utilized for calculating the parameters of antenna components such as Patch, Substrate, ground plane, and feed line. To compute the parameter values of the proposed antenna, some values required to define like Dielectric constant value, thickness of the substrate, Impedance value and resonance frequency. The proposed work employs FR4-epoxy as a substrate material which has the dielectric constant value of 4.4 and the thickness is considered as 1.6mm. Furthermore, the resonance frequency is considered as 3.5GHZ which is suitable for the application of dual or multiband antennas and the impedance value is taken as 50 Ω. Furthermore, the thickness of the patch and ground plane is taken as 0.0175mm. The equations for calculating the length and width of the patch are given below,

$$Pl = Pl_{eff} - 2\Delta Pl \tag{1}$$

$$Pw = \frac{c}{2f_{res}\sqrt{\frac{(\varepsilon_{res}+1)}{2}}} \tag{2}$$

Where, Pl is representing the length of the patch, Pw representing the width of the patch, ΔPl is representing the extension of length, Pl_{eff} is denoting the effective length, f_{res} is describing the resonance frequency, ε_{res} is denoting the dielectric constant value, and c is denoting the speed of the light which is 3×10^8. Here, the effective length Pl_{eff} and extension of length ΔPl is computed by utilizing the following equations respectively.

$$Pl_{eff} = \frac{c}{2f_{res}\sqrt{\varepsilon_{reseff}}} \tag{3}$$

$$\Delta Pl = 0.412h\frac{(\varepsilon_{reseff}+0.3)\left(\frac{Pw}{h}+0.264\right)}{(\varepsilon_{reseff}-0.258)\left(\frac{Pw}{h}+0.8\right)} \tag{4}$$

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Where, h is the height of the substrate, and ε_{reseff} is representing the effective dielectric constant which is estimated with the help of applying below given equation,

$$\varepsilon_{reseff} = \frac{\varepsilon_{res}+1}{2} + \frac{\varepsilon_{res}-1}{2}\left[1 + 12\frac{h}{Pw}\right]^{-1/2} \quad (5)$$

The aforementioned equations are utilized for calculating the length and width of the antenna patch. The following equation is applied for calculating the feed line length and width.

$$Fl = \frac{1}{4}\lambda_g \quad (6)$$

$$Fw = \frac{7.48\times h}{e^{\left(z_0\frac{\sqrt{\varepsilon_{res}+1.41}}{87}\right)}} - 1.25\times t \quad (7)$$

Where, Fl is representing the length of feed line, Fw is denoting the width of feed line, t is representing the thickness of the path material, and λ_g is denoting the guided wavelength which is computed by utilizing the below equation,

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{rseff}}} \quad (8)$$

Where, λ is representing the wavelength of the frequency and it is estimated by applying the below equation,

$$\lambda = \frac{c}{f_{res}} \quad (9)$$

After calculating the length and width of the feed line, the substrate length and width is computed by utilizing the following equations.

$$Sl = 6h + Pl \quad (10)$$

$$Sw = 6h + Pw \quad (11)$$

Where, Sl is denoting the length of the substrate and Sw is denoting the width of the substrate. For ground plane dimensions, the values which are obtained from substrate length and width are considered. The values which are obtained from the calculation are optimized to attain an optimal and effective result. The optimized design parameters are given in Table I.

TABLE I. OPTIMIZED DESIGNING PARAMETERS FOR PROPOSED FREQUENCY RECONFIGURABLE MPA

Variables	**Description**	**Optimized value (mm)**
Pl	Length of patch	19
Pw	Width of patch	26
Fl	Length of feed line	10
Fw	Width of feed line	1
FPl	Length of feed port	10
FPw	Width of feed port	3
Sl	Length of substrate	50
Sw	Width of substrate	50

The table 1 shows the optimized values for the proposed frequency reconfigurable microstrip patch antenna. Here, the length of the patch Pl is optimized to 19mm, width of the patch Pw is optimized to 26mm, length of the feed line Fl is optimized to 10mm, width of the feed line Fw is optimized to 1mm, length of the substrate Sl is optimized to 50mm, and width of the substrate Sw is optimized to 50mm. Additionally, the feed port is included to enhance the performance of the antenna which has the length FPl of 10mm and the width FPw of 3mm. Figure 1 illustrates the design of proposed frequency reconfigurable MPA with Shunt-series MEMS switch.

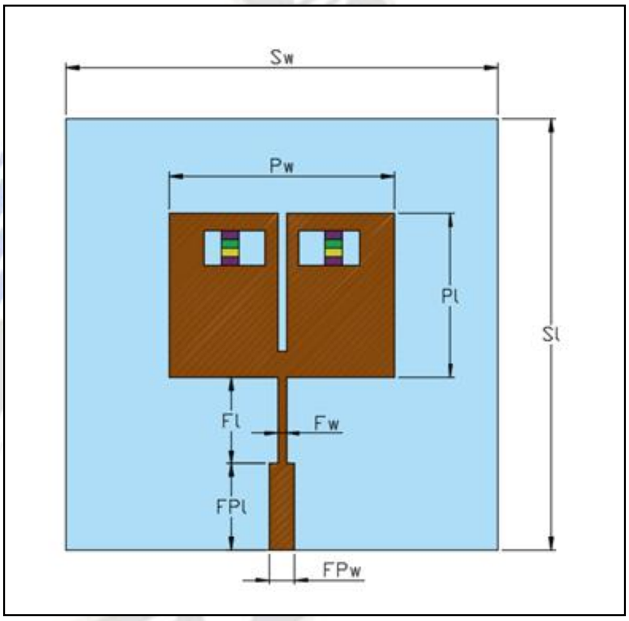

Figure 1. 2D Diagram for the Proposed Frequency Reconfigurable MPA

The proposed antenna contains two Shunt-series switches which have two capacitances, one resistance, and one inductance. It contains one series connection and one shunt connection. While increasing the value of capacitance and reducing the value of resistance is making the switch to ON condition. Similarly, while decreasing the value of capacitance and increasing the value of resistance is making the switch to OFF condition. Here, the capacitance, resistance, and inductance are taken as 1 µF, 1 µohm, and 0.4 nH for ON condition respectively. On other hand, for OFF condition, the capacitance, resistance, and inductance are taken as 0.5 pF, 1 Gohm, and 0.4 nH respectively.

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III. DESIGN PROCEDURE AND SIMULATION

This section discusses the procedure of design and simulation setups which are implemented for the proposed model. Here, the proposed frequency reconfigurable MPA with Shunt-series MEMS switch is designed with the help of the computer software named High-frequency structure simulation (HFSS) which is the platform of ANSYS. The implementation process is performed in the processor of i3 9th generation Intel core along with 8GB RAM system configuration and it has 3.60 GHz CPU speed.

A. Procedure

This section explains the designing procedures of the proposed frequency reconfigurable microstrip patch antenna by using the software platform of HFSS. At first, the substrate of the antenna is designed as per the optimized dimensions and configured the material as FR4-epoxy. After that, the patch is designed on the substrate with respected values and the feed line is designed as per the optimized values. Additionally, the feed port is designed with respected dimensions to enhance the efficiency of the proposed antenna. On other side of the substrate, the ground plane is designed which is fully cover the substrate's length and width. Furthermore, three slots are made over the patch to place the switching mechanisms and improve the efficiency. Here, two shunt-series MEMS switches are employed for the frequency reconfiguration process. Each switch contains two capacitance, one resistance, and one inductance for the switching process in the simulation. After placing the switches on their appropriate location, the impedance port is designed in terms of connecting the feed port and ground plane to transfer the frequency. To limit the radiation of the antenna, radiation box is designed which is Thereafter, the boundary conditions are applied for each component as per their respected boundaries. In terms of that, the patch, feed line, feed port, and ground plane are configured as perfect-E boundary. The switches are designed as each has 4 blocks and the switches are configured to lumped RLC boundary. Here, first block is configured as capacitance lumped RLC boundary with the value of 1 µF. Second block is configured as resistance with the value of 1 µohm and third block is configured as inductance with the value of 0.4 nH. Moreover, the last block is configured as same as first block and the value also similar to it. These configured values are set for the switch in ON condition. Likewise, the radiation boundary is configured for radiation box. Subsequently, the lumped port excitation is configured to the port and the impedance value is set as 50 Ω. Then, the analysis setup is configured with sweep graph range from 2 to 5 GHz and the resonance frequency is considered as 3.5 GHz. Here, three conditions such as ON-ON, OFF-ON, and OFF-OFF are acquired for the simulation process and the performance of the proposed antenna is validated with the help of utilizing metrics such as Return loss, Bandwidth, Gain, VSWR, and Radiation pattern.

B. Simulation Results and Analysis

In this section, the obtained results for the switching conditions of ON-ON, OFF-ON, and OFF-OFF based on Return loss, Bandwidth, Gain, VSWR, and Radiation pattern are analyzed. The obtained results are discussed in the following sections.

B. 1. Return Loss and Bandwidth

The Return loss and Bandwidth for the proposed antenna design is illustrated in figure 2 in terms of ON-ON switching condition.

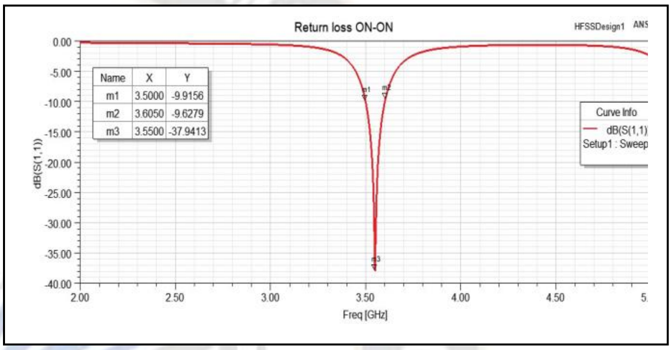

Figure 2. The Obtained Return Loss for ON-ON Condition

From the above graph (in figure 2), the obtained Return loss for the proposed antenna in ON-ON switching condition is -37.94 dB with the bandwidth of 0.1 GHz (3.6-3.5). In OFF-ON switching condition, the obtained return loss of proposed antenna design is demonstrated in figure 3.

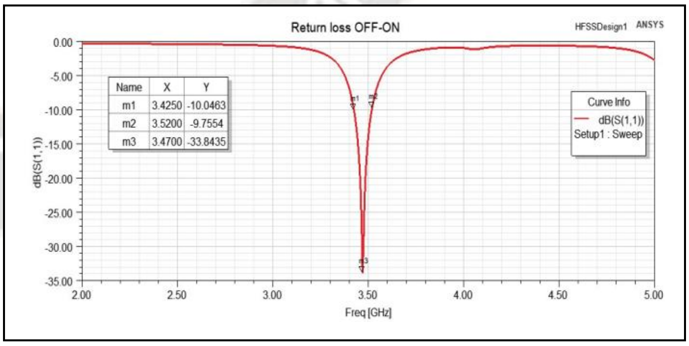

Figure 3. The Obtained Return Loss for OFF-ON Condition

The above shown diagram (figure 3) is illustrating that the proposed antenna design is attained -33.84 dB of return loss with bandwidth of 0.1 GHz (3.5-3.4) in OFF-ON switching condition. Similarly, the return loss for the OFF-OFF switching condition is demonstrated in figure 4.

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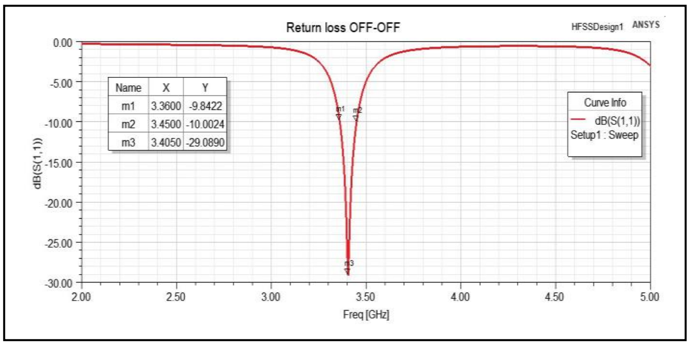

Figure 4. The Obtained Return Loss for OFF-OFF Condition

The above graph (figure 4) is shown that the proposed antenna design in OFF-OFF switching condition is obtained -29.09 dB return loss with 0.09 GHz (3.45-3.36) is obtained.

B. 2. Gain

The obtained gain for the proposed antenna design in ON-ON switching condition is illustrated in figure 5.

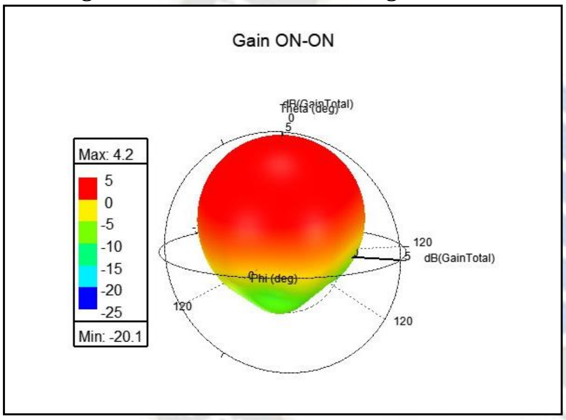

Figure 5. The Obtained Gain for ON-ON Switching Condition

As per the above diagram (in figure 5), the proposed antenna design is achieved 4.2 dB gain in ON-ON switching condition. The gain plot for the OFF-ON switching condition is shown in figure 6.

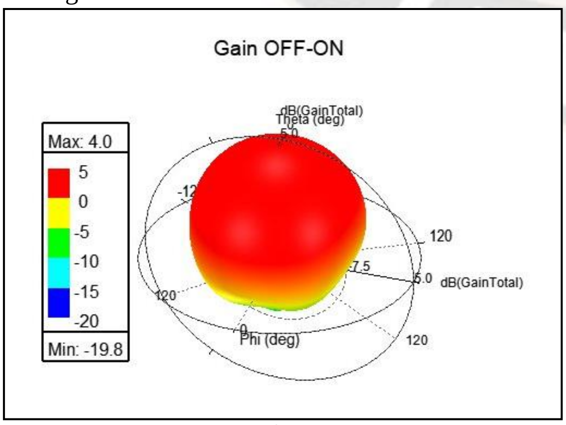

Figure 6. The Obtained Gain for OFF-ON Switching Condition

From the above figure (figure 6), in OFF-ON switching condition, the proposed antenna design is attained 4 dB of gain.

Likewise, the gain for the proposed antenna design in OFF-OFF switching condition is demonstrated in figure 7.

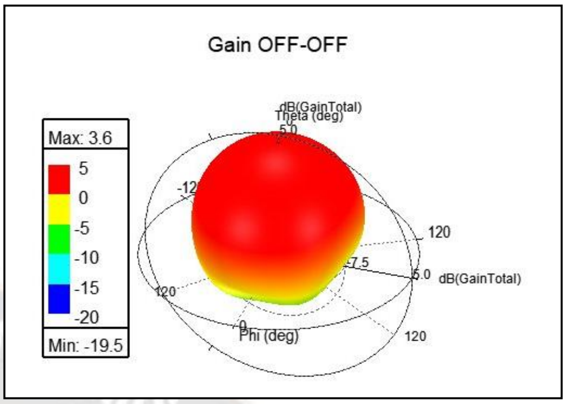

Figure 7. The Obtained Gain for OFF-OFF Switching Condition

The gain for the proposed antenna design in OFF-OFF switching condition is achieved 3.6 dB.

B. 3. VSWR

The acceptance level of VSWR is 1 to 2 and the obtained VSWR for the proposed antenna design in ON-ON switching condition is demonstrated in figure 8.

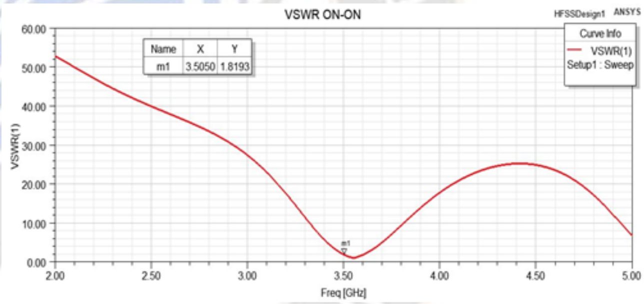

Figure 8. The Obtained VSWR for ON-ON Switching Condition

For ON-ON switching condition, the obtained VSWR for the proposed antenna design is 1.82 which is in the range of acceptance criteria. The VSWR for the OFF-ON switching condition is illustrated in figure 9.

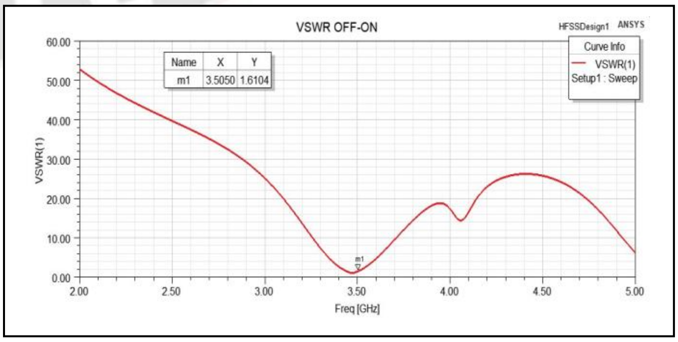

Figure 9. The Obtained VSWR for OFF-ON Switching Condition

As per the above graph (in figure 9), the VSWR in OFF-ON switching condition for the proposed antenna design is

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obtained as 1.6 which is also in the range of acceptance criteria. Similarly, the VSWR for the proposed antenna design in OFF-OFF switching condition is shown in figure 10.

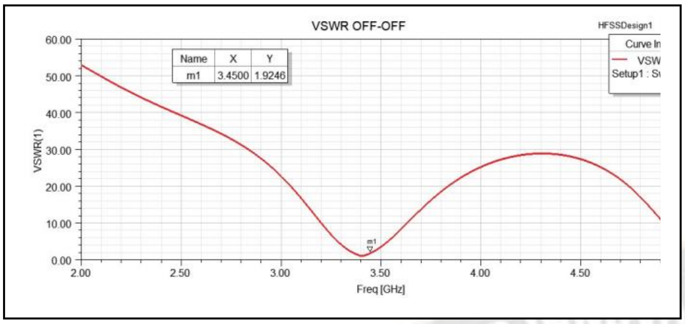

Figure 10. The Obtained VSWR for OFF-OFF Switching Condition

From the above graph (in figure 10), the obtained VSWR in OFF-OFF switching condition is 1.92 for the proposed antenna design which is also in the range of acceptance criteria.

B. 4. Radiation Pattern

The radiation pattern for the proposed antenna design in the switching condition of ON-ON is shown in figure 11.

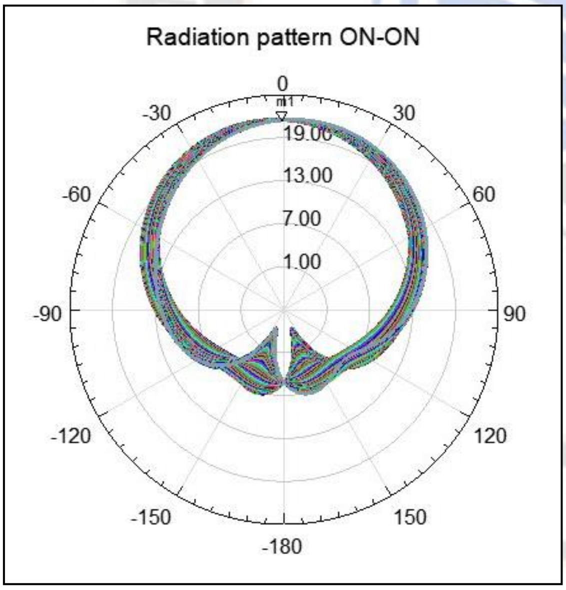

Figure 11. The Obtained Radiation Pattern for ON-ON Switching Condition

From the aforementioned diagram (figure 11), the radiation pattern is obtained as 21.27 dB for the proposed antenna design in ON-ON switching condition. The radiation pattern for the OFF-ON condition is shown in figure 12.

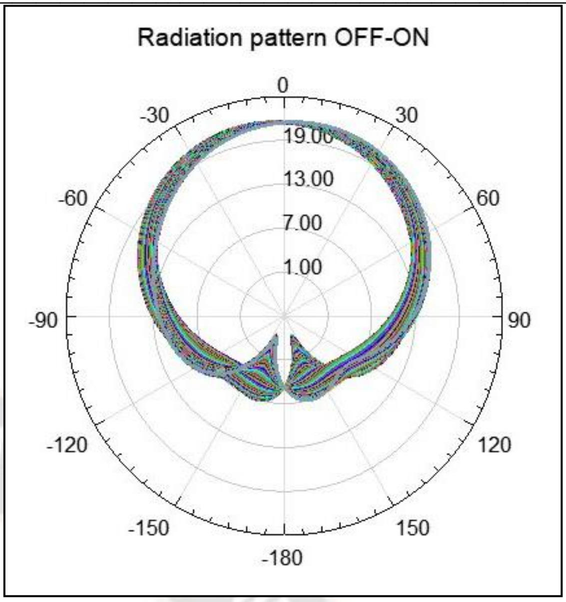

Figure 12. The Obtained Radiation Pattern for OFF-ON Switching Condition

As per the figure 12, the radiation pattern is attained as 21.48 dB in the switching condition of OFF-ON. Similarly, figure 13 shows that the obtained radiation pattern value for the proposed antenna design in OFF-OFF condition.

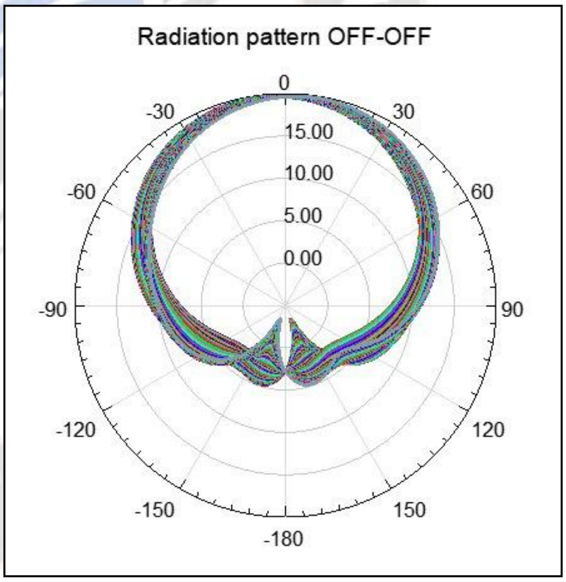

Figure 13. The Obtained Radiation Pattern for OFF-OFF Switching Condition

The above figure (figure 13) shows that the radiation pattern for the proposed antenna design is attained as 19.6 dB in the switching condition of OFF-OFF.

IV. COMPARATIVE ANALYSIS

In this section, Comparative analysis between the switching conditions such as ON-ON, OFF-ON, and OFF-OFF based on Return loss, Bandwidth, Gain, VSWR, and Radiation pattern for the proposed frequency reconfigurable microstrip patch

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antenna with Shunt-series RF MEMS switch. The obtained values for each metrics in each switching condition are given in table 2.

TABLE II. COMPARATIVE ANALYSIS FOR EACH METRICS UNDER VARIOUS SWITCHING CONDITIONS

Switching conditions	Return loss (dB)	Bandwidth (GHz)	Gain (dB)	Radiation pattern (dB)	VSWR
ON-ON	-37.94	0.1	4.2	21.27	1.82
OFF-ON	-33.84	0.1	4	21.48	1.61
OFF-OFF	-29.08	0.09	3.6	19.6	1.92

As per the above table (Table 2), ON-ON switching condition is performed well in the return loss with the value of -37.94 dB which lower than the switching conditions OFF-ON and OFF-OFF. In Bandwidth, ON-ON and OFF-ON switching conditions are equally performing with the value of 0.1 GHz which is higher than the OFF-OFF switching condition. For gain, the ON-ON switching condition is achieved 4.2 dB which is higher than the OFF-ON and OFF-OFF switching conditions. In Radiation pattern, the OFF-ON switching condition is attained 21.48 dB which is higher than other two switching conditions ON-ON and OFF-OFF. Moreover, the VSWR is achieved the acceptance range for these three switching conditions. From the above analysis, the proposed frequency reconfigurable microstrip patch antenna is performed efficiently in all switching conditions such as ON-ON, OFF-ON, and OFF-OFF and achieved better results in terms of Return loss, Bandwidth, Gain, VSWR, and Radiation pattern.

V. CONCLUSION

The main objective of this work is to develop an efficient microstrip patch antenna for the wireless communication system by tuning the frequency with the help of utilizing Shunt-series RF MEMS switch. Here, the HFSS software is employed for performing the design and simulation process with the switching conditions such as ON-ON, OFF-ON, and OFF-OFF. Furthermore, the Maxwell equations are employed for the computation of designing parameter values. At first, the microstrip patch antenna is designed with Shunt-series RF MEMS switch in HFSS. Thereafter, the simulation process is conducted based on three switching conditions such as ON-ON, OFF-ON, and OFF-OFF. The performance of the proposed antenna design is evaluated with the help of executing the antenna performance metrics such as Return loss, Bandwidth, Gain, VSWR, and Radiation pattern. The simulation outcomes are attained in terms of all three conditions based on the performance matrices. The final results are demonstrated that the proposed frequency reconfigurable microstrip patch antenna is more efficient and suitable for the wireless communication system.

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